Preliminary Laboratory Study of the Effects of Burial by AMAX/Kitsault Mine Tailings on Marine Invertebrates

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TABLE OF CONTENTS

	Page
LIST OF FIGURES	iv
LIST OF TABLES	iv
LIST OF APPENDICES	iv
ABSTRACT	v
RÉSUMÉ	vi
INTRODUCTION	1
MATERIALS AND METHODS	2
SEDIMENT COLLECTION	2
INVERTEBRATE COLLECTION	2
Subtidal Species	2
Intertidal Species	3
CONTINUOUS DEPOSITION STUDIES	4
STATIC BURIAL STUDIES	7
CHEMICAL ANALYSIS	9
RESULTS	10
SEDIMENT AND WATER CHEMISTRY	10
CONTINUOUS DEPOSITION STUDIES	11
Twenty-Eight Day Exposure	11
Eleven Day Exposure	11
STATIC BURIAL STUDIES	12
Yoldia thraciaeformis	12
Macoma calcarea	13
Sternaspis scutata	14
Chionoecetes bairdi	14
DISCUSSION	15
GENERAL OVERVIEW	15
Bivalves	15
Polychaetes	18
Crustaceans	19
FACTORS AFFECTING INVERTEBRATE ESCAPE ABILITY AFTER BURIAL	21
GENERAL DISCUSSION	23
ACKNOWLEDGEMENTS	27
REFERENCES	28

LIST OF FIGURES

		Page
FIGURE 1	Collection site for Amax/Kitsault mine tailings	31
FIGURE 2	Schematic representation of continuous deposition apparatus	32
FIGURE 3	Summary of static burial studies with Yoldia thraciaeformis, Macoma calcarea and Sternaspis scutata	33
FIGURE 4	Diagrammatic presentation of burrowing behaviour of a representative bivalve and polychaete	34
FIGURE 5	Bivalve foot types	35

LIST OF TABLES

TABLE 1	List of species tested during deposition studies	36
TABLE 2	Chemical and particle size characteristics of tailings and sediment	37
TABLE 3	Survival of test animals following 28 days of continuous tailings deposition	38
TABLE 4	Length, weight and condition factor of organisms following 11 days of continuous tailings deposition	39
TABLE 5	Summary of static burial studies with Yoldia thraciaeformis	40
TABLE 6	Summary of static burial studies with Macoma calcarea	41
TABLE 7	Summary of static burial studies with Sternaspis scutata	42

LIST OF APPENDICES

APPENDIX I	Amax tailings and marine sediment sampling locations	43
APPENDIX II	Water quality data for continuous tailings deposition studies	44
APPENDIX III	Lengths and weights of surviving bivalves from the 28 day continuous tailings deposition study	45

ABSTRACT

Reid, B.J. and J. Baumann, 1984. Preliminary laboratory study of the effects of burial by Amax/Kitsault mine tailings on marine invertebrates. Can. MS. Rep. Fish. Aquat. Sci. 1781: vi + 45 p.

Continuous and static sediment deposition studies were conducted with selected marine invertebrates using tailings from the Amax of Canada Ltd. molybdenum mine at Kitsault, B.C.. Four subtidal bivalve species (Yoldia thraciaeformis, Y. limatula, Macoma calcarea and Acila castrenensis) and one polychaete species (Sternaspis scutata) survived 28 day continuous deposition of mine tailings. Three species of intertidal bivalves (Mytilus edulis, Protothaca staminea and Venerupis japonica), and limited numbers of juvenile Tanner crabs (Chionoecetes bairdi) survived exposure to a continuous suspension of Amax tailings for nine days (bivalves) and eleven days (crabs) respectively. Static core burial studies with Y. thraciaeformis and M. calcarea resulted in few mortalities (≤8.3%) after 48 hour burial in up to 30 cm of Amax tailings or native sediments. Both species demonstrated an ability to migrate through 30 cm of either tailings or sediment. Migration ability or survival of Y. thraciaeformis and M. calcarea did not differ between burial in mine tailings or native sediments. Thirty cm of Amax tailings completely inhibited vertical migration of the polychaete Sternaspis scutata resulting in 75% mortality after 48 hours. Test results indicate that the critical burial depth of Amax tailings or native sediment preventing vertical migration of Y. thraciaeformis and M. calcarea is >30 cm, while the critical burial depth range of Amax tailings for S. scutata is between 20 and 30 cm. Results of laboratory studies are discussed in relation to the scientific literature and field data collected in the vicinity of Alice Arm.

RÉSUMÉ

Reid, B.J. and J. Baumann, 1984. Preliminary laboratory study of the effects of burial by Amax/Kitsault mine tailings on marine invertebrates. Can. MS. Rep. Fish. Aquat. Sci. 1781: vi + 45 p.

À l'aide de certains invertébrés marins, on a entrepris des études sur le dépôt continu et statique de sédiments en utilisant des stériles provenant de la mine de molybdène de Kitsault (C.-B.) appartenant à la société Amax of Canada Ltd. Quatre espèces de bivalves de la zone infralittorale (Yoldia thraciaeformis, Y. limatula, Macoma calcarea et Acila castrenensis) et une espèce de vers polychète (Sternaspis scutata) ont survécu 28 jours à un dépôt continu de stériles miniers. Trois espèces de bivalves de la zone intertidale (Mytilus edulis, Protothaca staminea et Venerupis japonica) et un nombre restreint de jeunes crabes de Tanner (Chionoecetes bairdi) ont survécu à l'exposition à une suspension continue de stériles de la mine Amax respectivement pendant neuf (bivalves) et onze jours (crabes). Suite aux études faites sur l'enfouissement statique des déchets avec Y. thraciaeformis et M. calcarea, quelques cas de mortalité (8.3%) ont été enregistrés après 48 heures d'enfouissement dans plus de 30 cm de stériles de la mine Amax ou de sédiments naturels. Les deux espèces se sont montrées capables de traverser 30 cm de stériles ou de sédiments. La capacité de migration ou la survie de Y. thraciaeformis et de M. calcarea ne différait pas, que l'enfouissement ait lieu dans les stériles miniers ou les sédiments naturels. Trente cm de stériles de la mine Amax étaient suffisants pour empêcher complètement la migration verticale du vers polychète Sternaspis scutata, entraînant un taux de mortalité de 75% après 48 heures. Les resultats des expériences indiquent que la profondeur critique d'enfouissement des stériles de la mine Amax ou des sediments naturels empêchant la migration verticale de Y. thraciaeformis et de M. calcarea est inférieure à 30 cm, tandis que l'échelle de la profondeur critique d'enfouissement des stériles de la mine Amax varie de 20 à 30 cm pour S. scutata. On discute des résultats des études effectuées en laboratoire par rapport aux données des ouvrages scientifiques et aux donnees recueillies sur le terrain dans les parages du bras Alice.

INTRODUCTION

During its initial nineteen months of operation (April 1981 - October 1982) the Amax of Canada Ltd. molybdenum mine deposited a total of 4 million tons (9,000 T/day) of tailings into Alice Arm, B.C. (Burling et al., 1983). The turbidity plume created during operation of the mine was expected to create areas of unstable bottom characterized by high rates of sediment deposition. A benthic faunal survey conducted in Alice Arm in October 1982 (Kathman et al., 1983) just prior to mine shutdown revealed a considerable reduction in mean density of taxa and number of individuals at stations approximately 2 km west of the outfall compared to 1977 data. Elimination of most benthic invertebrates near the tailings outfall correlated with tailings distribution data in Alice Arm based on sedimentation and sediment trace metal studies.

Several factors may account for decreased faunal abundance in Alice Arm after tailings deposition including heavy metal toxicity, increased turbidity reducing primary production, the clogging or abrading of respiratory surfaces by particulate material and burial.

This study is a preliminary experimental examination of the survival of marine invertebrates after continuous and static (catastrophic) deposition of mine tailings from the Amax/Kitsault mine.

MATERIALS AND METHODS

SEDIMENT COLLECTION

This study commenced after the Amax of Canada Ltd. molybdenum mine had ceased operating for eleven months. Since fresh mine tailings could not be obtained, previously deposited tailings were collected from two bottom sediment stations in Alice Arm (Figure 1) on October 8, 1983 using a stainless steel Smith-MacIntyre grab. Sediments at these locations were previously identified as having metal levels similar to the Amax tailings discharge (Goyette and Christie, 1982). The top 2 cm of each grab sample was discarded and the remaining sample placed in pre-cleaned (acid washed) 22 L polyethylene buckets for storage at 4°C until use. Equal portions of tailings from the two stations were composited and homogenized in a bucket for use in the experiment.

Marine sediments were collected from Satellite Channel (Saanich Inlet, B.C.) and English Bay (Vancouver, B.C.), using an Agassiz dredge and Smith-MacIntyre grab, respectively for each location. Sediments were placed in pre-cleaned polyethylene buckets and frozen until use. A sample of sediment from each location and the mine tailings composite was placed in individual "whirlpak" bags and frozen for trace metals, particle size and organic carbon analysis. Sampling station coordinates and sampling depths for mine tailings and sediments are presented in Appendix I.

INVERTEBRATE COLLECTION

Subtidal Species

Four subtidal clam species, one polychaete species and one crab species were used during this study. Species were representative of benthic invertebrate families reported from Alice Arm

(Table 1) during recent benthic and trawl surveys (Kathman et al., 1983, Demill, 1983). The clams Yoldia thraciaeformis, Y. limatula and Acila castrensis were collected off Boatswain Bank of Satellite Channel, B.C., using an Agassiz dredge. The clam Macoma calcarea and the polychaete Sternaspis scutata were collected in English Bay using a Smith-MacIntyre grab. Animals were immediately sieved from sediments and placed in plastic trays with cooled seawater for transport to the Department of Fisheries and Oceans' West Vancouver Laboratory. Animals collected from English Bay were transported within 3 hours to the laboratory. Bivalves collected from Satellite Channel were initially transported to the University of Victoria, placed in a flowing seawater bath (30 ppt, 10°C), then shipped to the West Vancouver Laboratory within 24 hours of collection. Upon receipt in the laboratory, specimens were transferred into plastic trays filled with their native sediments and placed in flowing unfiltered seawater (28 ppt, 10 ± 1°C).

Six juvenile (carapace width 4.0-6.0 cm) Tanner crabs (Chionoecetes bairdi) were collected from Hastings Arm in October, 1983 using an otter trawl. Crabs were held in aquaria with cooled seawater (30 ppt, 5°C) and subsequently air transported in plastic trays layered with wet paper towels in an ice-filled cooler. Upon receipt at the West Vancouver Laboratory, crabs were placed in a 150 L fiberglass tank with flowing seawater. Crabs were fed a mixture of frozen fish carcass and fresh mussels. An attempt was also made to transport to Vancouver live Yoldia thraciaeformis collected by otter trawl from Hastings Arm, however, the poor condition of these clams precluded their use in the experiments.

Intertidal Species

Mussels (Mytilus edulis) were collected from an intertidal location at Figurehead Point in Stanley Park, Vancouver, B.C. Limited numbers of clams (Protothaca staminea, Venerupis

japonica) found within mussel byssal threads were also retained (Table 1). Bivalves were transported to the lab in plastic trays filled with cooled seawater and placed in flowing seawater as previously described.

CONTINUOUS DEPOSITION STUDIES

An apparatus capable of delivering a tailings slurry at a controlled rate was constructed to simulate continuous tailings deposition in Alice Arm during operation of the Amax/Kitsault mine (Figure 2). The apparatus consisted of a refillable ABS plastic tube from which tailings were extruded with a neoprene piston on the end of a threaded rod. The rod was driven by a variable speed gear motor through a series of speed reducing sprockets and roller chains. The extruded tailings were mixed with a regulated flow of seawater by a plastic rotating brush and the slurry was directed to the test vessels through polyethylene tubing.

Seawater flow to the depositor was regulated by a glass metering tube in a constant head tank. Flow was set at 250 ml per minute to ensure a 90% molecular exchange of the water in the test vessel in 10 hours (Sprague, 1969), and to maximize settling of tailings particles.

The test and control vessels consisted of two identical fibreglass troughs (inside dimension: 150 x 20 x 35 cm), with a standpipe drain at one end which was separated from the main part of the vessel by a 27 cm high plexiglass partition (Figure 2). Both vessels were immersed in a flowing seawater bath to minimize temperature fluctuations.

Burling et al. (1983) reported that if tailings from the Amax mine settle over roughly 25% of Alice Arm at a daily deposition rate of 9,000 tons per day, average sedimentation would be approximately 1,500 $g.m^{-2}d^{-1}$. This deposition rate was chosen

for our study, as it represents a median in the range of sedimentation rates reported in Alice Arm during tailings discharge. Since the rate of delivery to the test vessel was based on volume, the specific gravity of the tailings was determined (APHA 1975) to aid in calculating delivery rates. Given a specific gravity of 1.7, the surface area to be covered with tailings, and the anticipation that some suspended tailings would be lost down the test vessel drains, a target delivery of 1,000 ml. m^{-2} d^{-1} equivalent to 11.8 ml.hr^{-1} was chosen.

Two deposition studies with test periods of 28 and 11 days were conducted with this apparatus. For the 28 day study, English Bay sediments were spread in a layer 3-4 cm deep in each vessel which were then filled with flowing seawater. For the 28 day study, each vessel was divided into two compartments by a 23.5 cm high plexiglass partition. The deposit feeding polychaete Sternaspis scutata (sedentariate) was introduced into one compartment of each vessel while the infaunal deposit feeding bivalves, Yoldia thraciaeformis, Yoldia limatula and Macoma calcarea, and the infaunal non-siphonate suspension feeding bivalve Acila castrensis were placed in the other compartment. The animals were left to acclimate for 7 days prior to starting the experiment. Numbers of individuals tested ranged from 7 to 30 depending on species (Table 3).

Specimens which had not burrowed after the 7 day acclimation period were considered moribund and removed. The depositor was then activated and allowed to discharge tailings for 28 days. Start-up problems resulted in intermittant tailings discharge during the first 6 days of operation. These problems were corrected and delivery was uninterrrupted thereafter.

After the 28 day deposition period, water flow was continued for 3 days to permit settling of suspended tailings and a visual examination of the sediment surface in each trough. Water was then siphoned and sediments screened to recover test animals. All

mortalities were recorded and live specimens were placed in plastic trays filled with English Bay sediments for a 24 hour observation period. After 24 hours the number of animals which did not reburrow or had died were recorded. Those animals which were dead or missing (compared to initial numbers) during recovery were considered mortalities. Survivors were measured for length and whole wet weight.

Apparatus and test conditions for the 11 day study were identical to those for the 28 day study, except that vessel compartments and initial mud substrates were not used. Juvenile Tanner crabs (Chionoecetes bairdi) which had been held in the laboratory for 4 months, were placed in the vessels (one in control, two in test) 3 days before the depositor was started. In addition, thirty mussels, (Mytilus edulis), and three to four each of the siphonate suspension feeding clams Protothaca staminea and Venerupis japonica were suspended in separate plastic baskets 5 to 7 cm off the bottom in each of the vessels (with crabs) 2 days after the depositor was started. The depositor was operated for 11 days, followed by 3 days of normal water flow.

After testing, the carapace width (CW) and wet weight of the crabs were recorded. Shell length (anterior/posterior) and soft tissue weights were recorded for bivalves. Condition factor (CF) for the bivalves was determined as follows (Beukema and Debruin, 1977):

$$CF = \frac{\text{wet soft tissue weight (g)} \times 100}{\text{Length}^3 \text{ (cm)}}$$

Condition factors for bivalves exposed to tailings were compared statistically to control specimens using the students "t" test. Internal tissues of P. staminea, V. japonica and crabs were visually examined under a dissecting microscope for abnormalities.

All tests were conducted under natural lighting. For all experiments, dissolved oxygen (YSI Model 51B), pH (Fisher portable), salinity (Goldberg, American Optical Refractometer) and temperature were measured at test initiation and twice weekly. One litre water samples for non-filterable residues (NFR) were collected on two occasions during the 28 day study and once during the 11 day study. Samples were collected by siphoning water through polyethylene tubing placed 15 cm below the water surface near the slurry or water entry point and at the surface near the drain standpipe (test vessel only). Samples were refrigerated until analysis.

STATIC BURIAL STUDIES

Static burial studies were conducted with the clams Yoldia thraciaeformis and Macoma calcarea and the polychaete Sternaspis scutata to determine the critical burial depth of tailings and native sediments (clams only) which would prevent vertical migration. All tests were conducted in a fiberglass trough with flowing seawater (250 ml/min). Individual test chambers for clams and polychaetes consisted of 5 cm diameter clear acrylic tubes fitted with a removable plastic cap on the bottom. Each tube was graduated at 1 cm intervals to determine vertical migration distances. A 5-6 cm layer of native sediment (Satellite Channel for Yoldia, English Bay for Macoma and Sternaspis) was placed in each tube, carefully covered with seawater and placed in the seawater trough. After 2 hours, two individuals of one species were added to each tube. A total of 12 individuals of each species (6 replicate tubes) were tested for each depth. Shell length (measured from the umbo) ranged from 7.0 - 13.0 mm for Y. thraciaeformis and 8.0 - 13.0 mm for M. calcarea. Animals were allowed to burrow and acclimate in the sediments for at least 24 hours. Animals failing to burrow during this time were considered moribund and discarded. In this case a new animal was placed in the tube and allowed to burrow before testing.

Prior to initiating tests, the tailings were slurried with seawater (ratio 1:5, water to tailings) to prevent clumping of tailings. The tailings slurry was carefully, but rapidly poured into each tube (within 30 sec.) to minimize disturbance of initial sediments. Native sediments were stirred as is (no water added) and poured over substrates in the same manner. Test depths included 0 (control), 5, 10, 20 and 30 cm. After burial, tubes were immediately returned to the flow-through seawater trough for observation. Behavioural observations and number of individuals contacting the sediment surface indicated by presence of siphons for clams, or gills and burrows for polychaetes, were recorded at 2, 4, 24 and 48 hours.

After 48 hours, vertical migration distances were determined by sieving 5 cm layers of sediments from each tube and recording the number of animals in each layer. Dead individuals were noted and removed and remaining live specimens placed in 100 ml beakers with native sediment for a 24 hour observation period. After 24 hours the number of animals which did not reburrow and/or had died were recorded.

Limited static burial tests with juvenile Tanner crabs (C. bairdi) were conducted in plastic pails (dimensions: 14.5 x 35 cm) placed in a 150 L fiberglass tank with flowing seawater. Preliminary tests with sediment placed in the bottom of the bucket were abandoned as the crabs stirred up the sediments prior to tailings deposition thereby preventing visual observations. Subsequent tests were therefore conducted without the use of initial substrates. One crab was placed in each of two test pails and and one control pail and left to acclimate for one hour. The tailings slurry previously described was placed on a 2 mm mesh screen on top of the bucket, then quickly but evenly pushed through the screen on top of the crabs. Due to the limited number of crabs and volume of Amax tailings available, only one test with a burial depth of 5 cm was conducted.

All tests were conducted under natural lighting. Test temperatures ranged from 8-10°C; salinity, 28-30 ppt; pH, 7.25-7.55; and dissolved oxygen, 8.0-8.9 mg/l. All parameters were recorded at the start and finish of each experiment using instruments previously described in continuous deposition studies.

CHEMICAL ANALYSIS

Sediment particle sizing was conducted by wet sieving sediments through a nest of sieves between 2.0 and 0.053 mm. Particles passing through the 0.053 mm screen were further classifed into silt and clay by the pipette method (Bindra and Hall, 1977).

Sediment samples for total organic carbon (TOC) analysis were air dried and pulverized prior to digestion. The dried samples were digested in HCl to remove carbonates and the digest filtered through LECO crucibles and re-dried. The residues were then analyzed for organic carbon by LECO Induction Furnace. Particle size distribution and organic carbon analysis was conducted by Pacific Soils Analysis Inc., Vancouver, B.C.

Metals were analyzed on unsieved samples at the West Vancouver laboratory of the Departments of Environment and Fisheries and Oceans using an Inductively-Coupled Argon Plasma Optical Emmission Spectrometer (ICAP) as described in the environmental laboratory manual of the Departments of Environment and Fisheries and Oceans, Pacific Region (Government of Canada, 1979). Fine definition for lead and cadmium analysis was determined using a Jarrell Ash 850 atomic adsorption spectrophotometer (AAS) with FLA 100 graphite tube furnace. Fine definition for arsenic was determined by hydride generation AAS. Standard Reference Materials BCSS-1 and MESS-1 for marine sediment were analyzed in the same manner.

Non-filterable residues (NFR) analysis on water samples from continuous deposition studies were determined gravimetrically as described in Government of Canada (1979).

RESULTS

SEDIMENT AND WATER CHEMISTRY

Results of particle size distribution, total organic carbon and metals analysis are presented in Table 2. The Amax tailings composite had a particle size distribution similar to English Bay sediments; Satellite Channel sediments were slightly coarser. All three sediments consisted mostly of silt-clay (<0.053 mm) fractions. Of the three sediments tested, Amax tailings had the highest levels of zinc, lead, cadmium, molybdenum and arsenic. English Bay sediments had highest levels of copper, nickel and iron. Water quality data for continuous deposition studies is presented in Appendix II.

CONTINUOUS DEPOSITION STUDIES

Twenty Eight Day Exposure

A total of 6,430 ml of tailings partitioned between two compartments was delivered to the test vessel at a rate of 10.6 $ml.hr^{-1}$; slightly less than the target of 11.8 $ml.hr^{-1}$. Results of NFR analysis indicate 735 ± 250 ml of tailings were lost in waste water, leaving 5,695 ± 250 ml as the actual amount deposited in the test vessel (mean depth: 2.1 ± 0.1 cm). This is equivalent to 1,460 ± 60 $g\ m^{-2}\ d^{-1}$, slightly less than the target of 1,500 $g.m^{-2}\ d^{-1}$.

Mounds were present below the input tubes in the tailings vessel indicating a large proportion of the slurried tailings settled very quickly. Deposition in the polychaete compartment was relatively constant away from the tailings input mound, however sediments in the bivalve compartment appeared churned and mounded throughout, presumably due to bivalve activity.

Test animal recoveries and mortalities are reported in Table 3. Lengths and weights of the test species are presented in Appendix III. No animals were found in the input mound in the polychaete compartment, however, six live Acila castrensis were recovered from the mound in the bivalve compartment. Mortalities were less than 10% for all species, except for Yoldia limatula, where one mortality occurred in the control vessel representing 14.3% of the population. Only one mortality (Macoma calcarea) was recorded from tailings exposed animals which represented 3.4% of the population.

All surviving animals readily reburied themselves during the 24 hour post experiment observation period.

Eleven Day Exposure

Length, wet weight and condition factor (bivalves) data for the species tested are presented in Table 4.

No mortalities occurred among the two crabs (C. bairdi) exposed to tailings. Both of these crabs and the control specimen appeared active and lively at the completion of the experiment. Examination of the gills with a dissecting microscope revealed clogging of the lamellae with particulate matter in the tailings exposed crabs. Gills of the single control crab were clean. Gill rakers were actively cleaning the gill lamellae after the carapace had been removed in all crabs. None of the crabs displayed any visible morphological abnormalities under microscopic examination.

No mortalities occurred in clams (P. staminea and V. japonica) or mussels (M. edulis) exposed to tailings for nine days. One mussel (3.4% mortality) died in the control tank. All mussels formed byssal fibre attachments to the baskets or each other. Clams were extending their siphons when observed during the study period. Physical examination of mussel and clam gill tissue

revealed no evidence of abrasion or other aberrations. The only abnormality observed for the two clam species tested was that the four tailings exposed P. staminea appeared less pigmented (tissues lacked orange coloration) and less firm than those of the controls. There was no significant difference ($p > 0.05$) in condition factor between control and tailings exposed mussels or clams at test completion.

STATIC BURIAL STUDIES

Results of static burial studies are summarized in Tables 5-7 and Figure 3. The burrowing behaviour of the bivalves and polychaete tested is described and illustrated in Figure 4.

Yoldia thraciaeformis

Yoldia thraciaeformis readily extracted itself after 30 cm burial of Amax tailings or native sediment. For all burial depths tested (5, 10, 20 and 30 cm) and both sediments, $\geq$ 83.3% of the individuals contacted the surface within 24 hours (Table 5). For some burial depths (tailings: 30 cm; native sediment: 5 and 20 cm), clams reached the surface within 2 hours. Mortalities after 48 hour burial in either sediment were $\leq$ 8.3% for any depth tested; no control mortalities were recorded. All survivors reburied and were alive after the 24 hour post experiment observation. All Yoldia tested had migrated from initial substrates into burial sediments after 48 hours. One dead individual was found on the sediment surface after burial in 5 cm of tailings, apparently expiring after contacting the surface. After 48 hours, at least 83.3% of Yoldia buried with mine tailings were found in the top 5 cm of sediment for each depth tested, with remaining 16.7% of organisms found in the next 5 cm (Table 5). Similarly $\geq$ 83.3% of Yoldia were present in the top 5 cm of sediment after 48 hr. burial in native sediments up to 20 cm, while only 66.6% of the clams were in the top 5 cm of sediment after 30 cm burial. There was no appreciable difference in mortalities

or numbers of surface contacts after 24 and 48 hours between the two sediments tested.

Clam migration routes were observed on the sides of some of the tubes. Clams contacting the surface extended their siphons, and in some cases were observed exhaling sediments. Some clams completely extracted themselves from both tailings or native sediments then reburrowed. Faeces or pseudofaeces were observed on the sediment surface at 48 hours in burial depths of $\geq$ 20 cm.

Macoma calcarea

M. calcarea readily extracted itself from Amax tailings and native sediment burial of 5 and 10 cm with at least 90% of the individuals contacting the sediment surface within 48 hours (Table 6). Only 75% of Macoma contacted the sediment surface after 48 hours burial in 20 and 30 cm for both sediments. Increased burial depth increased the length of time required for Macoma to contact the surface for both sediment types (Figure 3). For example, all of the Macoma buried with 5 cm of either sediment contacted the sediment surface within 24 hours compared to only 25.0% surface contact 24 hours after 30 cm burial. Only one mortality was observed in a clam buried with 5 cm of tailings. All surviving clams reburied within 24 hours during the post experimental observations and no additional mortalities were noted.

All Macoma buried with 5 cm of either sediment remained in the initial substrate, apparently contacting the surface by extending their siphons through the burial mud (Table 6). All but three clams buried with $\geq$10 cm of either sediment escaped the initial substrate, with the majority migrating to within 10 cm of the burial sediment surface. In general M. calcarea assumed a deeper position in both tailings and sediment compared to Y. thraciaeformis. No appreciable differences were observed in the number of surface contacts after 24 and 48 hours between the two sediment types.

As with Y. thraciaeformis, migration routes were observed on the sides of some of the tubes. Clams were observed feeding by extending their siphon and drawing sediments off the surface. In contrast to Yoldia none of the Macoma completely removed themselves from sediments.

Sternaspis scutata

Tests with S. scutata were conducted with mine tailings only. All worms buried with 5 and 10 cm of tailings contacted the sediment surface within 24 hours (Table 7). Fifty percent of the worms buried with 20 cm of tailings did not contact the surface after 48 hours, while none of the worms buried with 30 cm contacted the surface. Worms buried with 20 cm and 30 cm of tailings for 48 hours experienced 16.6% and 25% mortality respectively. A further 50% of the worms died after 30 cm burial in tailings during the 24 hour post experiment observation. The majority of worms buried with 5 cm of tailings were found in the initial substrate after 48 hours, although they had established surface contact prior to this (Table 7). In contrast 75% of the worms buried with 30 cm of tailings apparently did not leave initial substrates after burial.

Some worms contacting the sediment surface migrated out of their burrows then reburrowed. In one case a worm was observed at the sediment surface when the test was terminated, then migrated to a lower depth when the tube was disturbed. All worms observed at the surface were extending gills.

Chionoecetes bairdi

Both individuals of C. bairdi buried with 5 cm of tailings were observed on the sediment surface immediately after burial. Crabs were active and showed no delayed mortality after placement in fresh seawater.

DISCUSSION

GENERAL OVERVIEW

A detailed description of the expected physical behavior of Amax mine tailings during discharge into Alice Arm is presented in Burling et al. (1981). One feature observed during tailings deposition was the development of a turbidity plume where sediment concentrations may exceed 100 mg/l extending from the mine outfall down the deep central trench of Alice Arm Inlet (Burling et al., 1983). The physical impact of the turbidity current is to create unstable areas characterized by high rates of deposition. In general infauna and epifauna in Alice Arm are subjected to two types of physical disturbance during deposition of tailings; (a) catastrophic: characterized by high deposition rates (i.e., near outfall) and an unstable bottom (slumping), and (b) high turbidity: characterized by high suspended solids load and relatively stable bottom (ie. areas outside of the main turbidity plume).

This study investigated the effects of both catastrophic burial (static burial tests) and continuous deposition (high suspended solids) on selected marine invertebrates. The results are discussed in terms of each animal group examined.

Bivalves

The results of this study indicate that both Yoldia thraciaeformis and Macoma calcarea can migrate through 30 cm of mine tailings or native sediments after catastrophic burial. Compared to Yoldia however, fewer surface contacts were observed for M. calcarea 24 and 48 hours after burial in $\geq$20 cm of tailings or sediment. Low mortalities (8.3%) were observed for both clam species after burial, and are considered insignificant. Results indicate that the critical depth of Amax tailings or

native sediments preventing vertical migration of Y. thraciaeformis and M. calcarea over 48 hours is >30 cm.

Kranz (1974) investigated the sediment burial escape response of twenty five bivalves species including Yoldia limatula and Macoma nasuta. Y. limatula had approximately 90% success escaping >50 cm of native mud with a migration rate of 26.99 cm/hr. In contrast M. nasuta readily escaped from >36 cm of native silty sand and had a reduced migration rate of 2.09 cm/hr. These results are consistent with those obtained in the present study for Y. thraciaeformis and M. calcarea.

In general, Kranz (1974) found that deposit feeding bivalves could migrate greater distances than suspension feeders after catastrophic burial. Other studies tend to support these findings. For example, Galluci and Kawaratani (1975) found that 91% mortality occurred with the suspension feeding clam Transenella tantilla eleven days after burial in 8 cm of sand. Similarly, Chang and Levings (1976) found that the cockle Clinocardium nuttallii remained buried in 20 cm of sand after 24 hours. In contrast, Maurer et al. (1980) found that the deposit feeding clams Nucula proxima buried with 32 cm of silt-clay did not reach the surface within 8 days, and experienced high mortalities, while the suspension feeder Mercenaria mercenaria could migrate this distance with few mortalities.

Variations in organism morphology may explain differences in the observed escape response for Yoldia sp. and Macoma sp. For example, Yoldia sp. has a flared bifurcaced foot (Figure 5) which is ideally suited to the cohesive mud it inhabits, but is less useful for movements in coarser muds (Kranz, 1974). Macoma sp. on the other hand has a pointed foot which enables it to inhabit a broader range of sediments, but move less efficiently in any single type. Kranz (1974) also found that larger bivalves were better able to escape sediment burial than smaller individuals of

the same species, however, he did not find statistical differences in the ultimate depths each could escape. In the present study, differences in clam size were not considered a factor.

The results of our continuous deposition studies are in agreement with the reported tolerances of bivalves to catastrophic burial and suspended sediments. The depth of the tailings deposit (2.1 cm) observed during the 28 day continuous deposition studies was well within the tolerance range of the bivalves tested during the present static burial tests. In addition, several authors have reported that bivalves can tolerate suspended solids loads similar to those encountered in the present study (230 mg/L and 89 mg/L for 28 and 9 day studies respectively). For example, a recent study by Robinson et al. (1984) showed that suspended solid levels of >100 mg/L clay resulted in significant increases in pseudofaecal production and a decrease in the amount of food ingested by surf clams (Spisula solidissima). The clams, however, demonstrated an apparent acclimation to 100 and 500 mg/L clay showing greater mean chlorophyll consumption and digested chlorophyll levels after 21 days compared to 3 days exposure. Robinson suggested that turbidity producing discharges with suspended solids levels of $\geq$ 100 mg/L may have adverse effects on energetics of surf clam populations. Peddicord (1980) found that Mytilus californianus survived 15 days exposure to 2,100 mg/L of both suspended clean and contaminated sediment. Both of these studies suggest that higher concentrations of suspended tailings and longer test durations would be required to demonstrate mortalities in the species tested.

Several factors may have been responsible for the limp and colorless appearance of Protothaca staminea tissues after nine days exposure to suspended tailings. The clams may have ceased filtering when subjected to suspended tailings and weakened due to lack of food. These clams, however, were observed filtering on several occasions during the study suggesting that starvation

was not responsible for tissue deterioration. It is possible the high metal levels of the tailings adversely affected the clams resulting in some tissue breakdown. Larger sample sizes, longer test durations and histological examination would be required to provide definitive conclusions about this hypothesis.

Polychaetes

The sedentariate polychaete Sternaspis scutata exhibited reduced migration ability after burial with 20 cm of tailings, while burial with 30 cm of tailings resulted in virtually no migration and high mortalities. It is apparent 20-30 cm represents a critical depth range which will prevent vertical migration of S. scutata after burial in mine tailings.

Very limited information on the ability of polychaetes to escape burial is reported in the scientific literature. Salia et al. (1972) found that the errantiate polychaete Nephtys incisa was able to penetrate up to 21 cm of dredge spoil over a 48 hour period, whereas the sedentariate species Streblospio benedicti could not. Maurer et al. (1982) obtained similar results for the polychaetes Scoloplos fragilis (Sedentariate) and Nereis succina (Errantiate). Burial in up to 32 cm of silt-clay resulted in 45% mortality of S. fragilis compared to 16% in N. succina. Both of these studies are consistent with results of the present study which demonstrated the poor ability of the sedentariate polychaete S. scutata to escape and/or survive catastrophic burial.

Although published data indicate errantiate polychaetes can best survive sediment burial, a field study by McCauley et al. (1976) on the effects of maintenance dredging on four sedentariate polychaete species indicates varying adaptability to sediment instability. For example, the species Streblospio benedicti and Pseudopolydora kempi were found to be well adapted to sediments subject to continual overturn by currents, harbour activity and

high sedimentation. In contrast, Polydora ligni could tolerate frequent sediment turnover but not high sedimentation.

As with bivalves, morphological variation in the polychaetes may explain differences in ability to escape catastrophic burial. Pettibone (1963) suggests that polychaetes with distinct heads, and well developed parapodia and setae are normally considered excellent burrowers. For example, Nereis sp. and Nephtys sp. which are omnivorous and carnivorous respectively, have large setae which allow the worm to move rapidly through sediments in pursuit of prey (S. Byers, pers. comm.). In contrast, Sternaspis scutata has small setae at one end of the body and hooks on the other which enables it to maintain its position and feed off detritus, but move when required. This variation in setae number and size may dictate ability of polychaetes to survive catastrophic burial.

In this study, no mortalities occured amongst S. scutata after 28 days of continuous tailings deposition. McCauley et al. (1976) found that the sedentariate polychaete Capitella capitata was well adapted to areas subjected to sedimentation but not frequent turnover (i.e., catastrophic burial). Based on our continuous deposition studies it is apparent S. scutata is similarly adapted to some sedimentation, but not catastrophic burial as demonstrated in our static burial tests.

Crustaceans

Our study has demonstrated that juvenile Tanner crab (C. bairdi) can survive burial in 5 cm of tailings or eleven days continuous tailings deposition.

Literature on the effects of catastrophic burial on crabs is limited. Chang and Levings (1976) found that 20 cm of sand prevented upward movement of Cancer magister resulting in death within 5 days, while all crabs buried with $\leq$10 cm contacted the surface

within 24 hours. McElderry (1982) found that 80% small and 48% large C. magister remained buried 24 hours after burial with >20 cm mud. Maurer et al. (1981) found that the crab Neopanope sayi died within one day after burial with 16 cm of silt clay. Results of C. magister studies are consistent with results of the present study which indicate C. bairdi is able to survive 5 cm burial.

Presumably those crab species which normally burrow would best survive catastrophic burial due to adaptations for burial and subsequent unburial. Chang and Levings (1976) noted that C. magister after burial with sand did not crawl through the sediment, but pushed the carapace upwards to contact the surface. The weight of overburden and large vertical distance (relative to the push distance of the legs) to the new substrate surface would prevent crabs from reaching the surface. It is possible that C. bairdi may avoid areas of heavy deposition or burial events due to their mobility. Unfortunately, the burial depth tested in this study (5 cm) was not sufficient enough to permit detailed observation of C. bairdi escape behaviour.

As with the 28 day continuous deposition study, the depth of tailings deposited during the eleven day study (<1 cm) was not sufficient to bury juvenile Tanner crabs. Also the continuous exposure of the crabs to suspended tailings was not lethal during this study period. Limited information on the effects of continuous suspended sediments on crabs was found in our search of the literature. Peddicord (1980) reported that suspended contaminated sediment concentrations <4300 mg/L were not lethal to juvenile C. magister over 25 days exposure, however, 15% of the molting crabs were deformed. Peddicord reported that mortalities occurred in sediment concentrations of >9200 mg/L within 9 days; 92% of the deaths occurred during molting.

It is apparent that greater burial depths, higher suspended tailings concentrations than those tested (89 mg/L), or longer exposure durations would be required to cause mortality in C. bairdi.

FACTORS AFFECTING INVERTEBRATE ESCAPE ABILITY AFTER BURIAL

Organisms buried with sediments such as mine tailings must cope with several physical and chemical factors which may affect their ability to escape. The physical characteristics of the tailings such as particle size distribution, density and cohesiveness may alter escape responses. For example Kranz (1974) and Maurer et al. (1978) found that burial of certain species of bivalves, polychaetes and crustaceans with sediments of a different particle size than their preferred habitat drastically reduced escape ability and increased mortalities. In particular, Kranz (1974) found that escape response of labial palp deposit feeders (Yoldia sp.) was reduced after burial in fine sand compared to mud. In our study the particle size distribution was similar between tailings and native sediments which may explain why similar results were obtained with these two burial materials. However, during active tailings discharge in Alice Arm, Burling et al. (1981) predicted that larger (heavier) particles would fall near the outfall thereby creating a particle size gradient throughout the deposition zone. The changes in particle size from previous sediment may reduce escape ability of some infauna, leading to mortalities.

Nichols et al. (1978) found that poor escape response of animals buried in a soft bottom community was correlated to overburden stress, a measure which relates bulk sediment density and burial depth. When overburden stress reaches a critical value, an animal cannot initiate an escape response. For example, with bivalves, overburden stress reaches a critical level when the animal cannot open its valves to extend its foot and escape. Similarly, with polychaetes, overburden stress becomes critical when the worm cannot contract its body to move through sediments. In our study, overburden stress may have been responsible for the reduced migration ability of the polychaete S. scutata after burial in 20 and 30 cm of tailings.

The turbidity plume present during tailings deposition in Alice Arm creates a zone of uncohesive unstable sediments extending from the outfall down the central trench of the inlet (Burling et al., 1983). This unstable sediment may not be dense enough to support the weight of organisms attempting to move upwards to re-establish contact with overlying water (Peddicord, 1980). Animals attempting to escape this uncohesive sediment would die due to exhaustion or smothering.

The chemical properties of the sediment such as interstitial dissolved oxygen, temperature, salinity and sediment metal content may also affect escape response. Kranz (1974) found that salinity, temperature and oxygen concentration had an effect on bivalve escape ability only at the extreme end of its tolerance range. Presumably anoxic conditions in the burial sediment would be lethal if the animal could not establish surface contact after burial. Maurer et al. (1978) found that more polychaetes, amphipods and clams migrated after burial when tested in summer temperatures compared to winter temperatures. In the present study, temperature, salinity and oxygen were constant and at levels similar to the species natural environment and would not have adversely affected escape ability.

The main chemical difference between the sediments tested was metal content (Table 2). The tailings had much higher levels of lead, zinc and cadmium compared to the two native sediments tested. No previous data comparing escape response of invertebrates buried with clean versus contaminated sediment was found in our search of the literature. It has been demonstrated that increased sediment metal levels can reduce rate of burrowing in bivalves (McGreer, 1979; Phelps et al., 1983). It is apparent in this study that vertical migration and escape response of Y. thraciaeformis and M. calcarea was not reduced by the higher metals in the mine tailings compared to native sediments.

GENERAL DISCUSSION

During mine operation (April 1981 - October 1982) several otter trawl studies (DeMill, 1983) and one benthic survey (Kathman et al., 1983) were conducted and provide useful field data on impacts of tailings deposition on benthos in Alice Arm.

Our laboratory results and literature findings suggest that of the bivalve species tested, Yoldia sp. would best tolerate catastrophic mine tailings burial. Macoma sp. would not survive as well due to demonstrated poorer migration ability. Similarly, our laboratory results suggest that the four subtidal bivalve species tested (Y. thraciaeformis, Y. limatula, M. calcarea, A. castrensis) would survive short term (28 day) continuous deposition at a rate similar to average deposition in Alice Arm. It should be emphasized that tailings deposition rates in Alice Arm will be variable and exceed those tested in our study in areas close to the outfall. Therefore, results of laboratory studies may differ from field observations.

Benthic grabs conducted in June 1977 prior to mine startup indicate Yoldia spp. were present in Alice Arm sediments (density 10-60 m^2) at a site approximately 2 km west of the present outfall (O'Connell and Byers, 1978). An examination of trawl data 7 months after initial tailings discharge into alice Arm also revealed large numbers of Y. thraciaeformis and, to a lesser extent, Macoma sp., 2 km west of mine outfall (DeMill, 1983). These species, however, were not present in benthic grabs collected near the same site in October 1982, just prior to when discharges ceased (Kathman et al., 1983). Kathman's benthic survey indicated that only the bivalves Transenella tantilla and Nucula tenuis were present in very few numbers in the central trench, 2 km from the outfall. Of these two species, Nucula tenuis were present at this station prior to start-up. Kathman's survey also indicates that the number of bivalves were generally lower at stations closer to the outfall and in the central trench

compared to margins of the bottom of Alice Arm. Since the tailings plume travels down the centre of Alice Arm, reductions in benthic fauna are probably due to high deposition in the central trench compared to the inlet margins.

The dominance of both Transenella tantilla and Nucula tenuis in the central trench and margins suggest both of these species are adapted to tailings deposition in Alice Arm. Although Galluci and Kawaratani (1975) demonstrated that T. tantilla does not survive catastrophic burial, this species was found by Maurer (1967) to be well adapted to high turbidity and a variety of sediment conditions as would be encountered in Alice Arm during active tailings deposition. Nucula tenuis is from the same family (Nuculidae) as Acila castrensis, which survived 28 day continuous deposition in our study. N. tenuis is also apparently well adapted to high turbidity conditions. The fact that Yoldia sp. and Macoma sp. were still present (alive; condition not determined) after 7 months of tailings deposition in Alice Arm suggests they were capable of tolerating high turbidity and deposition rates over the short term. The absence of these species 19 months after mine start up (Kathman et al., 1983) however suggests that deposition rates may have surpassed their escape ability. However, factors other than burial such as heavy metal toxicity, low levels of organic carbon (food) and changes in substrate type, may be involved in elimination of these species.

Our results indicate that the intertidal/upper subtidal bivalve species, Mytilus edulis, P. staminea and V. japonica can survive short term exposure to suspended tailings. Since these species are found in intertidal/upper subtidal areas which are typically not subjected to suspended tailings, the physical impact of the tailings discharge on these species in Alice Arm will be negligible. However, should conditions prevail (due to pipe breakage or unusual currents) it is apparent these species might not die over short term exposures, although sublethal effects due to exposure to metals within the tailings could occur.

Our lab studies suggest the sedentariate polychaete S. scutata would not survive catastrophic burial from tailings deposition. Kathman et al. (1983) reported that the errantiate polychaete Nephtys cornuta cornuta was the dominant species in Alice Arm after 19 months of tailings discharge. The dominance of Nephtys is consistent with published literature which suggest errantiate polychaetes can best survive catastrophic burial. Trueman and Ansell (1969) indicate that Nephtys sp. are well adapted to conditions of shifting bottom sediments as would be encountered in Alice Arm during tailing disposal. It is interesting to note that our test species Sternaspis scutata in October, 1982 was only found just inside the sill at the entrance to Alice Arm, which is removed from the area of active tailings deposition (Kathman et al., 1983). However, a benthic survey conducted prior to mine startup (June 1977) found S. scutata in densities ranging from 20-70 m^{-2}, 2 km west of the outfall (O'Connell and Byers, 1978). The disappearance of S. scutata at this station may be a function of its inability to migrate through large tailings deposits as demonstrated in our lab studies.

Tanner crabs (Chionoecetes bairdi) have been reported in variable numbers in trawls conducted near the tailings outfall during periods of active discharge (DeMill, 1983). Jewett et al. (1983) found Tanner crabs to be the most abundant crab species in Alice Arm in November 1982, shortly after discharges ceased. Although our lab studies indicate juvenile Tanner crabs can survive burial in 5 cm of tailings and continuous deposition for eleven days, it is difficult to assess whether the crabs are capable of moving fast and far enough to escape entrainment in the turbidity plume during tailings discharge in Alice Arm. However, due to their high mobility (compared to infauna) Tanner crabs may not be directly affected by tailings burial. This hypothesis would have to be substantiated through detailed field studies during active tailings discharge to be conclusive.

Our experiment comparing escape response of bivalves buried with mine tailings and native sediments revealed no substantial difference in migration ability or survival. The higher metal levels found in the tailings does not appear to adversely affect escape ability of the bivalves over the short term. This does not exclude the possiblity that over long term exposure stress induced by the metals would inhibit escape ability.

In conclusion, results of this preliminary study suggest that the composition of benthic fauna in Alice Arm may be related to the tolerance of specific organisms to deposition of tailings in Alice Arm. The unstable characteristics of the bottom turbidity plume during discharge will create variable conditions of unstable substrate, high deposition and altered particle size distribution. These conditions will favour benthic species adapted to high turbidity and variable substrate particle sizes such as the polychaete Nephtys and the bivalve Transenella tantilla. Migratory epifauna such as Tanner crabs may not be directly affected by burial of mine tailings due to their high mobility and possible ability to avoid areas of high deposition, however, this has not been substantiated in field or laboratory studies. This also does not exclude the possibility that long term exposure to suspended tailings is harmful to the crabs. It is also apparent from this study that the adaptive capability of invertebrates and the complex chemical and physical factors in Alice Arm during tailings discharge may act synergistically. These synergistic factors increase the difficulty in predicting tolerances of the invertebrates to continuous tailings deposition in Alice Arm.

Future studies should investigate the long term chronic effects of continuous suspended tailings on migratory epifauna such as King crabs, Tanner crabs or shrimp.

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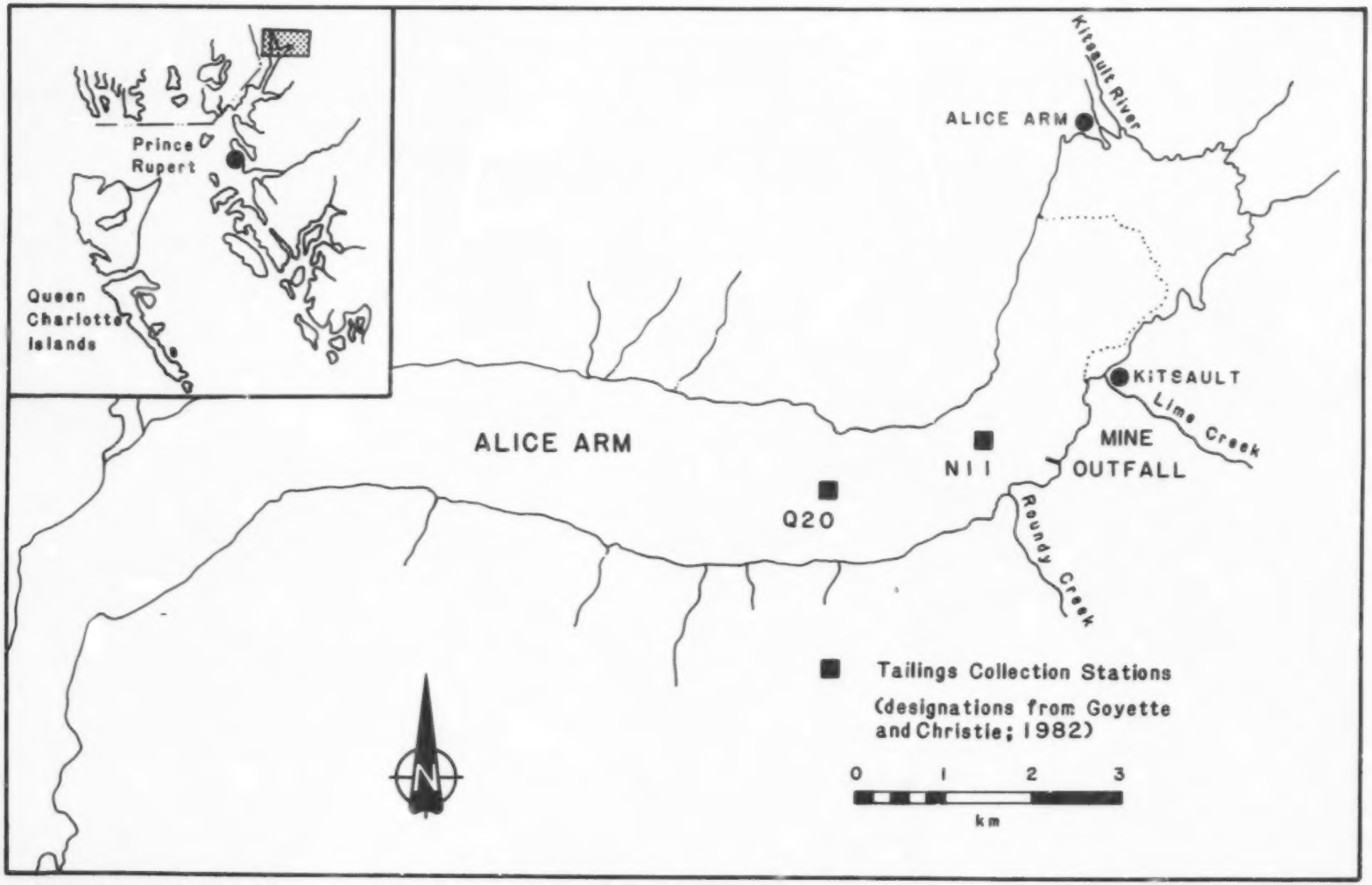

FIGURE 1. Collection site for Amax/Kitsault mine tailings.

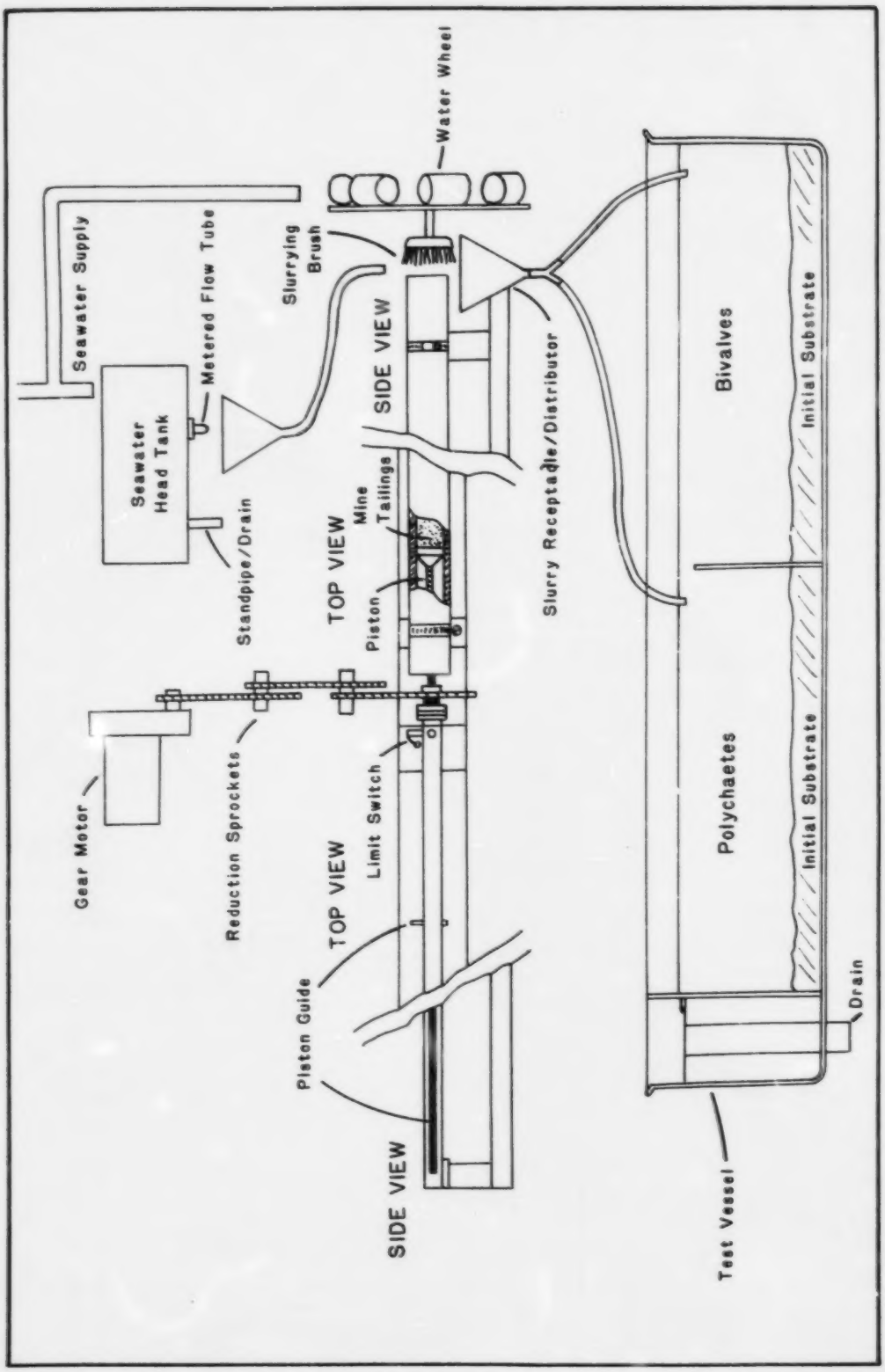

FIGURE 2. Schematic representation of continuous deposition apparatus. (Note: The substrate and polychaete/bivalve partition were removed for the 11 day study)

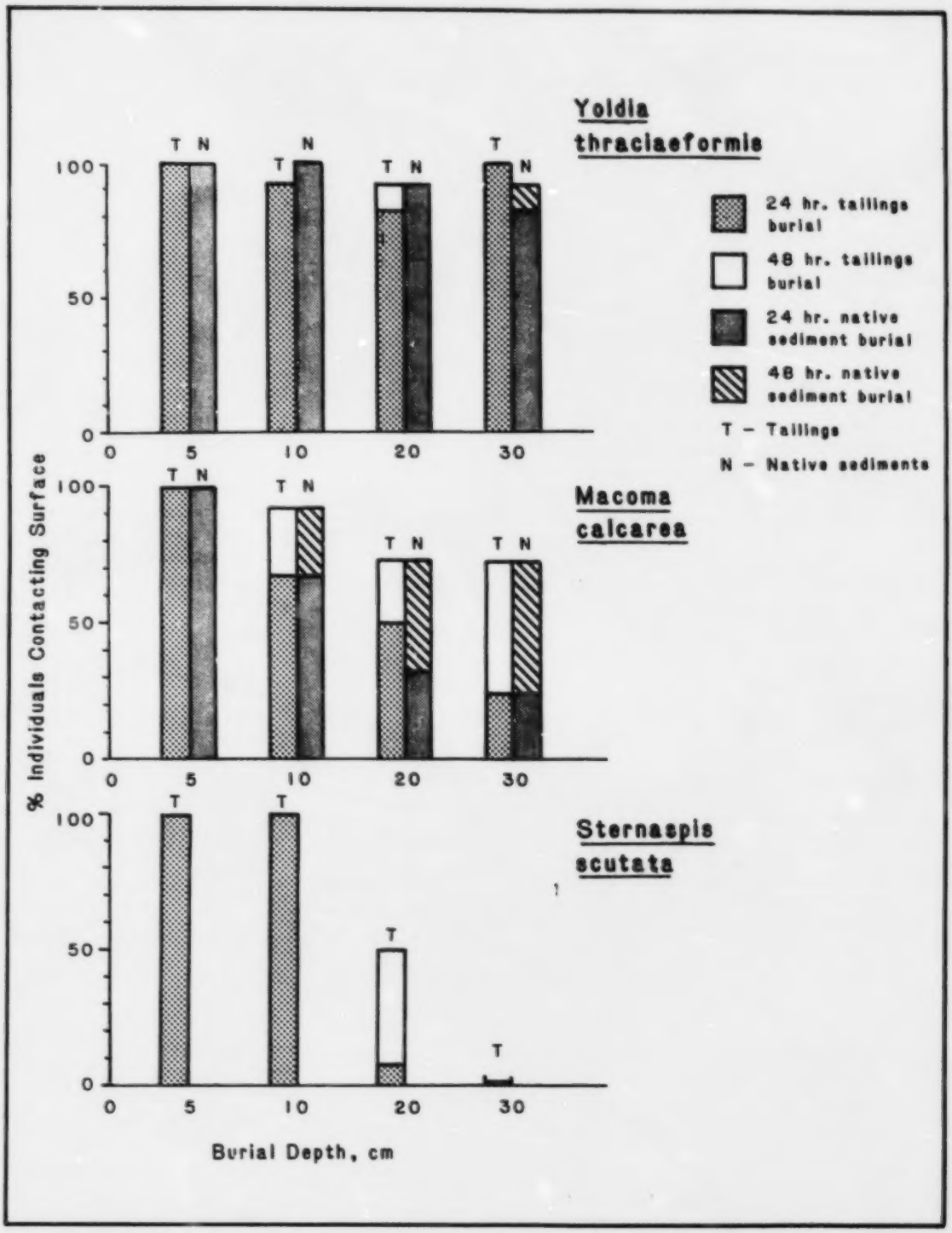

FIGURE 3. Summary of static burial studies with Yoldia thraciaeformis, Macoma calcarea and Sternaspis scutata.

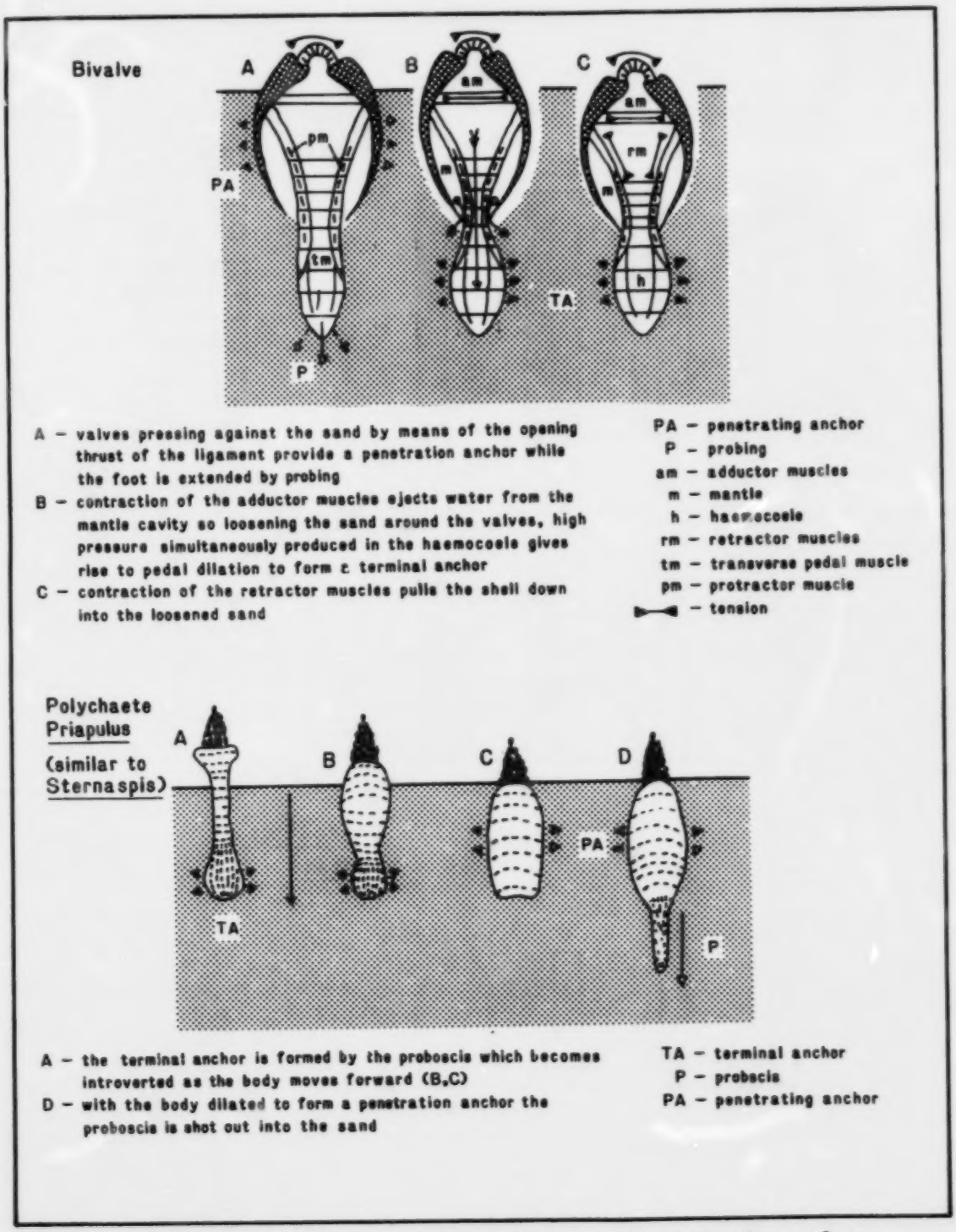
Bivalve
A
B
C
am
pm
rm
m
PA
tm
h
TA
P
A – valves pressing against the sand by means of the opening thrust of the ligament provide a penetration anchor while the foot is extended by probing
B – contraction of the adductor muscles ejects water from the mantle cavity so loosening the sand around the valves, high pressure simultaneously produced in the haemocoele gives rise to pedal dilation to form a terminal anchor
C – contraction of the retractor muscles pulls the shell down into the loosened sand
PA – penetrating anchor
P – probing
am – adductor muscles
m – mantle
h – haemocoele
rm – retractor muscles
tm – transverse pedal muscle
pm – protractor muscle
– tension
Polychaete
Priapulus
(similar to
Sternaspis)
A
B
C
D
TA
PA
P
A – the terminal anchor is formed by the proboscis which becomes introverted as the body moves forward (B,C)
D – with the body dilated to form a penetration anchor the proboscis is shot out into the sand
TA – terminal anchor
P – proboscis
PA – penetrating anchor

FIGURE 4. Diagramatic presentation of burrowing behaviour of a representative bivalve and polychaete . (After Trueman and Ansell, 1969)

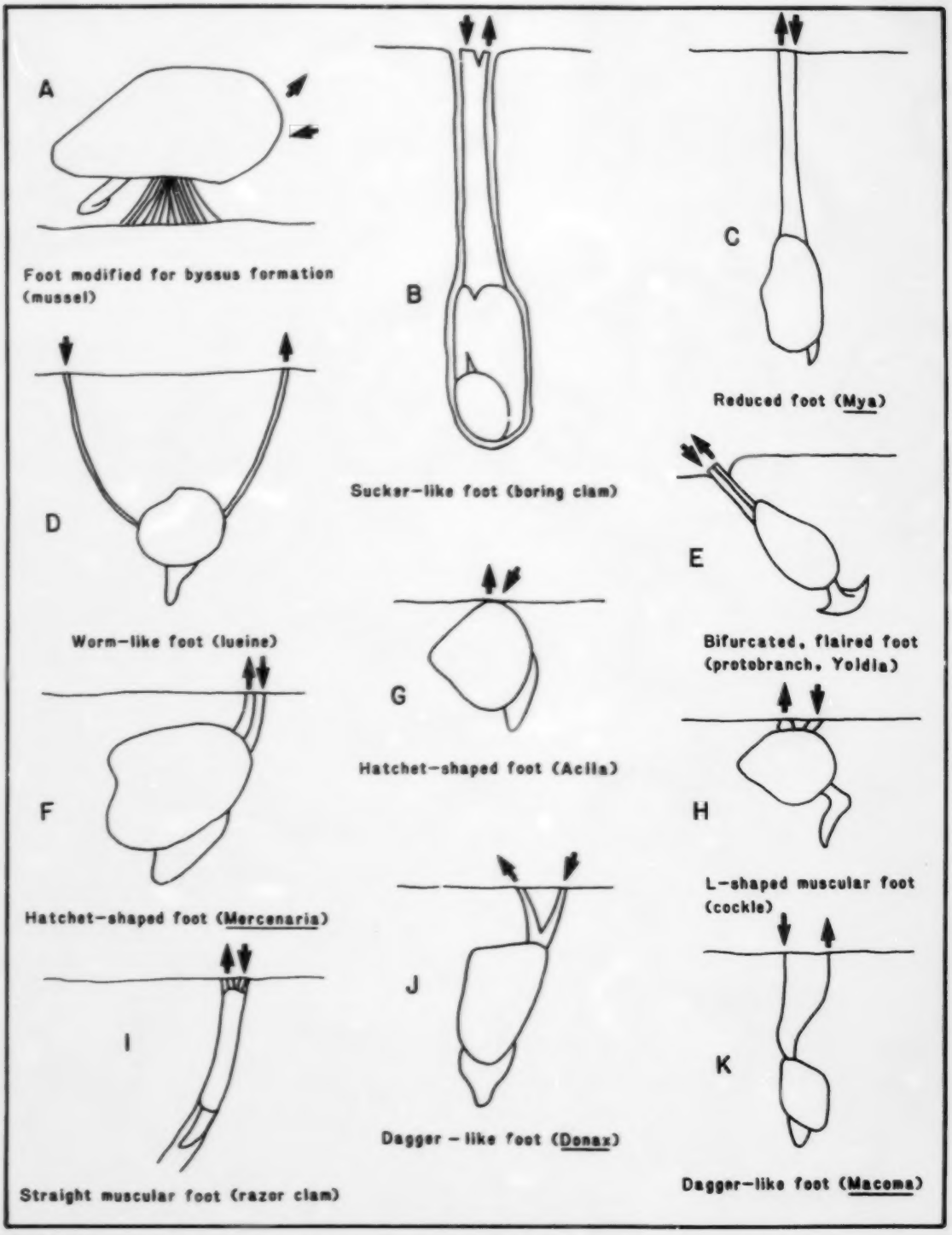

FIGURE 5. Bivalve foot types. (Adapted from Kranz, 1974)

TABLE 1. List of species tested during deposition studies.

Class	Family	Test Species	Comparable Species Found in Alice Arm	Reference	Habitat	Feeding Type	Test Type
Bivalvia	Yoldiidae	Yoldia thraciaeformis	Y. thraciaeformis/ Y. monterayensis	Demill, 1983	Subtidal Infaunal	Labial palp deposit feeder	-28 day continuous -static burial
		Yoldia limatula	Yoldia sp.	Kathman et al., 1983			
	Tellenidae	Macoma calcarea	Macoma sp.	Kathman et al., 1983 Demill, 1983	Subtidal, Infaunal	Siphonate deposit feeder	-28 day continuous -static burial
	Nuculidae	Acila castrensis	Nucula tenuis	Kathman et al., 1983	Subtidal, Infaunal	Non-siphonate suspension feeder	-28 day continuous
	Veneridae	Venerupis japonica	Transenella tantilla	Kathman et al., 1983	Intertidal, Subtidal, Infaunal	Siphonate suspension feeder	- 9 day continuous
		Protothaca staminea					
	Mytilidae	Mytilus edulis	Mytilus edulis	Goyette & Christie, 1982	Intertidal, Subtidal, Epifaunal	Non-siphonate suspension feeder	- 9 day continuous
Polychaeta	Sternaspidae	Sternaspis scutata	S. scutata	Kathman et al., 1983	Subtidal, Infaunal	Deposit feeder	-28 day continuous -static burial
Decapoda		Chionoecetes bairdi	C. bairdi	Demill, 1983	Subtidal, Epifaunal	Scavenger	-11 day continuous -static burial

TABLE 2. Chemical and particle size characteristics of tailings and sediments.

Parameter		Amax Tailings	English Bay sediment	Satellite Channel sediment
Organic Carbon (%)		0.66	2.23	1.40
Particle Size (%)				
Very coarse	(<2-1mm)	0	0.2	1.3
Coarse	(<1-0.5)	0	0.6	2.3
Medium	(<0.5-0.25)	1.0	1.6	10.9
Fine	(<0.25-0.125)	5.7	5.1	15.3
Very fine	(<0.125-0.053)	20.6	9.7	12.2
Silt	(<0.053-0.002)	59.1	55.3	40.0
Clay	(<0.002mm)	13.6	27.5	18.0
*Metals (mg/dry kg)				
Cd		11.2	0.45	0.36
Cu		74.3	314.0	31.1
Pb		233.5	48.5	74.3
Zn		440.0	165.0	102.0
Mo		171.0	5.8	1.1
Mn		825.0	441.0	298.0
Ni		15.5	43.0	26.0
Fe		26900.0	36000.0	31475.0
As		2.18	1.97	1.16

*Metals analyses of Amax tailings and English Bay sediments based on mean of 2 replicate analyses conducted on one sample; metal analysis of Satellite Channel sediment based on mean of 4 replicate analyses of one sample.

TABLE 3. Survival of test animals following 28 days of continuous tailings deposition.

Test Animal	Treatment	Initial Numbers	Numbers Recovered	Live Recovered	Mortality %
Acila castrensis	Test	21	21	21	0
	Control	20	20	20	0
Yoldia thraciaeformis	Test	10	10	10	0
	Control	10	10	9	10%
Y. limatula	Test	7	7	7	0
	Control	7	6	6	14.3%
Macoma calcarea	Test	29	28	28	3.4%
	Control	30	30	30	0
Sternaspis scutata	Test	20	20	20	0
	Control	15	14	14	6.3%

Table 4. Length, weight and condition factor of organisms following 11 days of continuous deposition.

Test Animal	Treatment	Exposure Duration (d)	N	Mortalities	Mean** Length (cm)	Mean*** Weight (g)	Condition Factor
Mytilus edulis	Test	9	30	0	3.2±0.8*	1.58±0.90*	2.2±0.4*
	Control	9	30	1	4.2±0.5	1.73±0.75	2.4±0.8
Protothaca staminea	Test	9	4	0	2.0±0.5	1.13±0.61	4.6±1.4
	Control	9	3	0	2.6±0.3	0.77±0.18	4.6±0.6
Venerupis japonica	Test	9	3	0	2.9±0.8	0.96±0.65	3.6±0.5
	Control	9	3	0	3.2±0.8	1.58±0.90	4.3±0.4
Chionoecetes bairdi	Test	11	2	0	4.9(4.8-5.1)	35.7(33.0-38.3)	-
	Control	11	1	0	6.0	70.3	-

* ± one standard deviation
** Length = anterior/posterior (bivalves), carapace width (crabs)
*** Weight = wet soft tissue (bivalves), whole body (crabs)

TABLE 5. Summary of static burial studies with Yoldia thraciaeformis

Burial Material	Burial Depth (cm)	N	Surface contacts from end of dumping (hours) (0-2)	(2-4)	(4-24)	(24-48)	Buried at 48 hours	Migration distance at 48 hours (cm) (-5-0)	(1-5)	(6-10)	(11-15)	(16-20)	(21-25)	(26-30)	Organisms Contacting Surface (%) 24h	48h	Organisms in Initial Substrate @ 48h (%)	Organisms in Burial Sediment @ 48h (%)	Mortalities (%) @ 48h
Amax Mine Tailings	0	24	-	-	-	-	-	24							100.0	100.0	100.0	0	0
	5	12	0	7	5	10	0	0	12*						100.0	100.0	0	100.0	8.3
	10	12	0	6	5	0	1	0	1**	11					91.7	91.7	0	100.0	0
	20	12	0	5	5	1	1	0	0	0	*2**	10			83.3	91.7	0	100.0	8.3
	30	12	3	9	0	0	0	0	0	0	0	0	0	12	100.0	100.0	0	100.0	0
Satellite Channel Sediments	0	24	-	-	-	-	-	24							100.0	100.0	100.0	0	0
	5	12	2	4	6	0	0	0	12						100.0	100.0	0	100.0	0
	10	12	0	5	7	0	0	0	0	12					100.0	100.0	0	100.0	0
	20	12	3	3	5	0	1	0	*1**	0	1	10			91.7	91.7	0	100.0	8.3
	30	12	0	4	6	1	1	0	0	0	0	0	*3**	8	83.3	91.7	0	100.0	8.3

* Location of dead individual after 48 hours
** Location of individuals not contacting surface after 48 hours

TABLE 6. Summary of static burial studies with Macoma calcarea

Burial Material	Burial Depth (cm)	N	Surface contacts from end of dumping (hrs) (0-2)	(2-4)	(4-24)	(24-48)	Buried at 48 hours	Migration distance at 48 hours (cm) (-5-0)	(1-5)	(6-10)	(11-15)	(16-20)	(21-25)	(26-30)	Organisms Contacting Surface (%) 24h	48h	Organisms in Initial Substrate @ 48h (%)	Organisms in Burial Sediment @ 48h (%)	Mortalities (%) @ 48h
Amax Mine Tailings	0	12	-	-	-	-	-	12							100.0	100.0	100	0	0
	5	12	0	0	12	0	0	12*							100.0	100.0	100	0	8.3
	10	12	0	0	8	3	1	1**	9	2					66.7	91.7	8.3	91.7	0
	20	12	0	0	6	3	3	0	2	0	5	5			50.0	75.0	0	100	0
	30	12	0	0	3	6	3	0	0	0	1**	1**	2**	8	25.0	75.0	0	100	0
Satellite Channel Sediments	0	12	-	-	-	-	-	12							100.0	100.0	100	0	0
	5	12	0	4	8	0	0	12	0						100.0	100.0	100	0	0
	10	12	0	0	8	3	1	2	5	5					66.7	91.7	8.3	91.7	0
	20	12	0	0	4	5	3	0	0	2**	4**	6			33.3	75.0	0	100	0
	30	12	0	1	2	6	3	0	1**	0	1**	1**	4	5	25.0	75.0	0	100	0

* Location of dead individual after 48 hours
** Location of individuals not contacting surface after 48 hours

TABLE 7. Summary of static burial studies with Sternaspis scutata

Burial Material	Burial Depth (cm)	N	Surface contacts from end of dumping (hrs) (0-2)	(2-4)	(4-24)	(24-48)	Buried at 48 hours	Migration distance at 48 hours (cm) (-5-0)	(1-5)	(6-10)	(11-15)	(16-20)	(21-25)	(26-30)	Organisms Contacting Surface (%) 24h	48h	Organisms in Initial Substrate @ 48h (%)	Organisms in Burial Sediment @ 48h (%)	Mortalities (%) @ 48h
Amax Mine Tailings	0	12	-	-	-	-	-	12							100.0	100.0	100.0	0	0
	5	12	0	0	12	0	0	10	12						100.0	100.0	83.3	16.7	0
	10	12	0	0	12	0	0	0	4	8					100.0	100.0	0	100.0	0
	20	12	0	0	0	6	6	* 2**	* 2**	2**	0	6			0	50.0	16.7	83.3	16.7
	30	12	0	0	0	0	12	* 9**	* 2**	1**	0	0	0	0	0	0	75.0	25.0	75.0

* Location of dead individual after 48 hours
** Location of individuals not contacting surface after 48 hours

APPENDICES

APPENDIX I: Amax tailings and marine sediment sampling locations.

Sediment	Station	Coordinates	Depth (m)
Amax Tailings	N11	55° 27.0'N, 129° 30.25'W	164
	Q20	55° 26.7'N, 129° 31.9'W	265
Satellite Channel	Boatswain Bank	48° 42.0'N, 128° 32.0'W	60-80
English Bay	West Vancouver	49° 20.0'N 133° 13.5'W	44

APPENDIX II: Water quality data for continuous tailings deposition studies

Parameter	Treatment	Time (Days):	28 day study								11 day study			
			0	4	10	14	17	21	24	28	31	0	4	8	11
pH	Tailings		*	*	7.4	7.3	7.4	7.5	7.3	7.2	7.3	7.4	7.6	*	*
	Control		*	*	7.4	7.3	7.4	7.5	7.3	7.3	7.3	7.5	7.5	*	*
Dissolved Oxygen (mg/L)	Tailings		8.6	8.5	8.6	8.8	8.9	9.6	8.2	9.1	9.8	8.6	8.5	9.0	8.7
	Control		8.6	8.5	8.4	8.8	9.6	9.7	8.3	9.4	9.6	8.4	7.1	9.1	7.9
Salinity (0/00)	Tailings		29.0	29.0	29.0	29.0	29.0	30.0	30.0	29.0	30.5	30.0	30.0	30.0	30.0
	Control		29.0	29.0	29.0	29.0	29.0	30.0	30.0	29.0	30.5	30.0	31.0	29.0	29.0
Temperature (°C)	Tailings		8.5	8.5	9.0	7.0	8.9	8.0	8.0	8.4	8.0	8.5	9.0	8.2	9.0
	Control		8.5	8.5	9.0	6.9	8.7	8.0	8.0	8.4	8.3	8.5	9.0	8.3	8.8
NFR (mg/L)	Tailings Bottom		-	-	-	215.0	-	-	-	246.0	-	-	89.0	-	-
	Tailings Drain		-	-	-	53.0	-	-	-	108.0	-	-	91.0	-	-
	Control		-	-	-	13.5	-	-	-	5.0	-	-	25.0	-	-

* Not recorded - instrument malfunction

APPENDIX III: Lengths and weights of surviving bivalves from the 28 day continuous tailings deposition study.

Species	Treatment	Mean Length* ± SD (mm)	Mean Weight** ± SD (g)	N
Macoma calcarea	Tailings	11.0 ± 3.4 (6.4 - 17.5)	0.63 ± 0.47 (0.12 - 1.98)	25***
	Control	11.2 ± 2.4 (7.1 - 15.4)	0.61 ± 0.40 (0.14 - 1.71)	30
Yoldia thraciaeformis	Tailings	9.7 ± 3.4 (6.4 - 16.7)	0.45 ± 0.45 (0.08 - 1.69)	10
	Control	8.6 ± 2.6 (6.4 - 14.2)	0.60 ± 0.79 (0.09 - 2.44)	9
Yoldia limatula	Tailings	8.5 ± 1.6 (7.1 - 11.1)	0.37 ± 0.20 (0.18 - 0.72)	7
	Control	8.3 ± 1.5 (6.4 - 10.3)	0.35 ± 0.17 (0.18 - 0.60)	6
Acila castrensis	Tailings	12.9 ± 1.6 (11.1 - 15.9)	1.9 ± 0.40 (0.52 - 1.96)	21
	Control	12.7 ± 1.2 (11.1 - 15.9)	0.97 ± 0.26 (0.62 - 1.70)	20

* Length = measured from umbo
** Weight = soft parts and shell
***Shells of 3 individuals which were alive were damaged during recovery and not included in length/weight determinations